Determination of thermal conductivity of tissue mimicking gel

A thesis submitted in partial fulfillment

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In

Biotechnology

By

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Certificate

This is to certify that the thesis entitled. "*Determination of thermal conductivity of tissue mimicking gel"* submitted by Mr. Satyendra Yadav in partial fulfillment of the requirements for the award of Bachelor of Technology Degree in Biotechnology at National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by him under my guidance.

To the best of my knowledge the matter embodied in the thesis has not been submitted to any University/Institute for the award of any Degree or Diploma

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Date:

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Abstract

Determination of thermal conductivity of tissue mimicking gel by varying the concentration (0.6%, 1.4%) and temperature from 60°C - 80°C to find the thermal conductivity by means of setup designed by us. The setup was calibrated and the distance of each thermocouple wire was fixed. It is found that the thermal conductivity is dependent on both the concentration as well as the temperature. The thermal conductivity of water agarose gel decreases with increase in the concentration and increases linearly with increase in the temperature. The proposed experimental set up is novel and simple which provides the reasonable value of thermal conductivity. To mimic biological tissues, the sample is prepared with a concentration of 0.6% (w/v) and 1.4% (w/v) of agarose in water.

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Chapter 1

Introduction

Chapter 1

Introduction

Heat transfer plays a very important role in biological systems, for example, thermoregulation where the body continuously exchanges heat with the environment but still maintains a constant inner body temperature. When heat is applied to any material it diffuses through the material and moves through it in the form of thermal current. The speed with which the heat diffuses through the material depends on the composition of the atoms. Also, this movement of heat depends on the coefficient of thermal conductivity of the material. Each material possesses a unique value of thermal conductivity. A higher thermal conductivity infers that heat diffuses very quickly through the material and vice-versa. Thus, determination of the thermal conductivity of biological materials like tissues is of great significance as there is plethora of heat transfer processes occurring at the physiological level.

There are various factors which need to be considered for choosing a particular technique for thermal conductivity measurement such as the geometry of the tissue, the sample size which should be a small volume so as to limit the variation in thermal conductivity. Also, if the samples are large in numbers the technique must be simple and must not require a very long measurement time. A lot of methods are available for the determination of thermal conductivity. In the steady state method like the hot plate technique, the sample is placed between two parallel plates, one being heated and the other one kept at a fixed temperature. For ensuring that there is no radial heat transfer, the sample is surrounded by a ring of thermal insulator [1]. Although, this is an accurate and simple method but it does not allow the measurement of transient temperature inside the sample. Further, semi-invasive techniques have been used where the thermocouples are inserted into the tissue with a contact heater which can also be used for determining the thermal conductivity. This method gives an advantage of temperature measurement with depth but the proper positioning of the thermocouple for temperature measurement is a serious problem. Due to ease in its usage, the non-invasive techniques have been used more widely. In vivo thermal inertia of muscle, skin and fat was evaluated using the same [2]. Also, non-invasive technique was used to investigate the thermal inertia of various gels, by measuring the variation in temperature on the opposite surface of disk shaped sample to that surface which was heated [3]. But this technique can help in evaluating the average thermal inertia at the surface and cannot be used for finding out the temperature at varied depths inside the tissue. With the advent in technology, the invasive probe technique has overtaken the most commonly used hot plate method and parallel plate method [4]. The invasive probe method utilizes a heat source inserted into the tissue along with the temperature sensor for determining the thermal history inside the tissue. The heated thermocouple and hot wire probe are the invasive probes that have been used to monitor the effective thermal conductivity of blood flow in different organ system [5-7]. Transient technique such as the hot wire method are quite popular owing to its low measurement time. Not only can this technique be used for fluids [8-12] but also for solid with 1% uncertainties [13].

Thermal conductivity of materials and its thermo physical properties are also essential for understanding the transport processes during food processing such as heating and drying, cryosurgical operations, and laser tissue interactions. Several methods have been used extensively for determining these values for granular starch and protein, gels and their gelatinized forms [14]; thermal properties of natural and cooked foods, biomaterials, gels have also been measured [15]. Since, the thermal conductivity varies as the temperature changes it is necessary to calculate the thermal conductivity over a wide range of temperature. Most of the thermal conductivity data of biological materials in the literature were conducted at atmospheric pressure. In this study, the thermal conductivity of agarose gels has been studied and it has been used for because it closely resembles the real biological tissue and has thermo physical properties equivalent to biological tissues, i.e it is an excellent tissue mimicking gel phantom.

Agarose is obtained from agar, which has undergone purification. Agar consists of unbranched polysaccharides obtained from the cell walls of many species of red seaweed (Gelidiaceae and Gracilariaceae). It is being used in the following ways:

1. In biological sciences and food-engineering research, agar gel has numerous practical applications. It acts as bacterial culture support and separation media in column chromatography and electrophoresis i.e a very useful re agent in analytical techniques.

2. Used in medicine and pharmacy.

3. In the food industry, it is used as a thickening agent, a vegetarian gelatin substitute, or a clarifying agentin brewing. Many kinds of dessert gel with agar have been used in traditional cooking. Agar forms a thermo-reversible gel in aqueous solution, and the gel is stable over a

wide temperature range; the gelation temperature is a crucial parameter when the starting point of gelation is considered.

These gels have a gelling or setting temperature close to 313 K and a melting temperature near 363 K [16-17]. The solid matrix ensures that the gels have excellent mechanical properties, while the large water content makes the transport of diffusive ions possible. There exists a study on the thermal conductivity of water-agar gel with different concentrations at various temperatures [18] but not with the novel experimental set up which.is proposed in this work. Also, a very simple, cheap and efficient set up has been designed to measure the thermal conductivity. The experimental results thus obtained with the novel set up were matched with the numerical predictions confirming that the results are in good agreement with the theoretical values. The overall aim of this work was to determine the thermal conductivities of water-agar gel with different concentrations at various temperatures. The specific objectives of this research are:

(1) To design a simple system for determination of thermal conductivity which is simple, fast, accurate, and convenient, and

(2) To predict numerically the values for the thermal conductivity of water-agar gel at different concentrations and various temperatures and correlate it with experimental values.

Chapter 2

Material and Methods

Chapter 2

Material and methods

Materials

i. Agarose powder (HIMEDIA): The gels made of agarose are having a thermal conductivity close to that of skin tissue.

ii. K-type thermocouple (Chromel-Alumel): K-type thermocouples are used for general laboratorial purpose. Thermocouples are available in the range of-200◦C to +1200◦C. Sensitivity is approximately equal to 41 µV /◦C.

iii. Distilled water: In chemical and biological laboratories distilled water is preferred to carry out the experiments

iv. Advantech portable data acquisition module (USB-4704): It is used as an interface between the thermocouple and the computer. Real time monitoring of temperature is achieved by the data acquisition module

v. Thermocol is known as polymerizing styrene. Thermocol is thermoplastic material which is used as a insulator in which chance of heat loss is minimum And scientific name of thermocol is Styrofoam.

vi. Ribbon is also used for the gripping of the thermocouple wire with the Styrofoam.

Methods

Gel preparation:

0.6% and 1.4% agarose gel was used during our experiment, because the thermal conductivity of the gel with these composition mimics the human tissues. The gel was prepared by mixing 0.3 grams of agarose powder (HIMEDIA) in 50 mL of distilled water and then flask was kept in the microwave oven. The solution was heated (about 3-4 minutes) till it becomes completely clear and transparent, i.e. there should not be any visible single floating particles inside the solution. During the heating, we should be careful about ourselves, we should not get injured. The flask was frequently stirred after 30 sec to mix the solution homogeneously. After that the solution was allowed to cool. Before it gets solidified, pour the gel in the setup which we have designed. The thermocouples are placed in such a manner so that one thermocouple should be at the middle plane (symmetry plane) of the sample and remaining two thermocouples lie at a distance of 3mm from the exposed surface of the sample.

Experimental setup

i. Simple apparatus to determine the thermal conductivity using Styrofoam and thermocouple wire.
ii. Data acquisition module.
iii. Breadboard.
iv. The overall setup connected with computer.

Simple apparatus to determine the thermal conductivity using Styrofoam and thermocouple wire.

A setup is designed which is shown in the figure2.1. It consists of styrofoam and thermocouple wires. The setup is prepared by fixing the thermocouple wires at the desired locations inside the sample. For this purpose, an adhesive is used which restricts the movement of thermocouple wires. The thermocouple wire is fixed inside the styrofoam by wrapping it with the ribbon so that it should not get displaced from its position. The depth of groove is 40 mm and length and breadth is (20 mm, 20 mm).

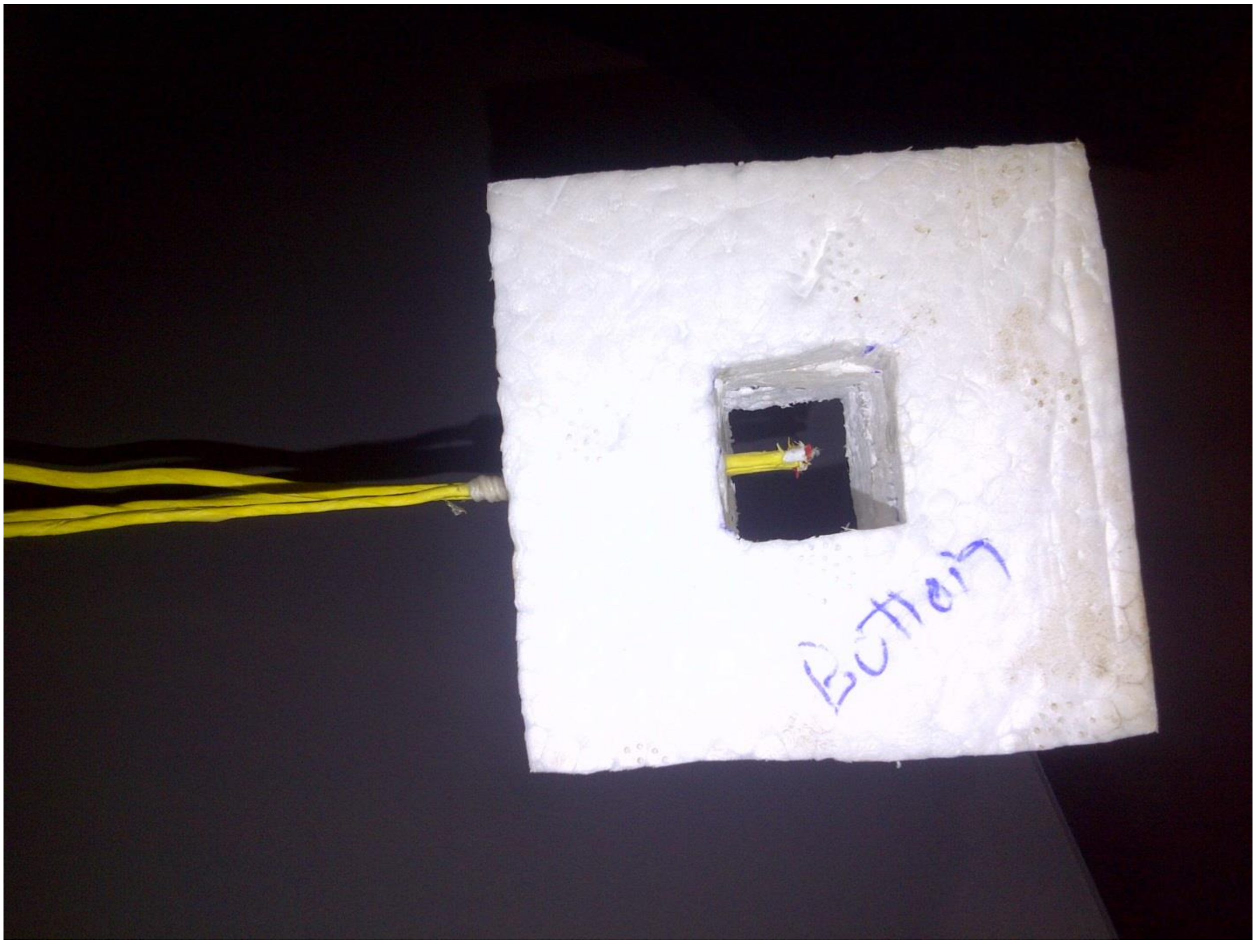

Figure 2.1: the set-up with three thermocouple wire get attached at the center and two extreme corners.

Data acquisition module

Thermocouple wire acts as a transducer which converts the temperature variations to variations in the voltage. These voltage variations are achieved using an Advantech portable data acquisition module (USB-4704). Generally the voltage values detected in the data acquisition module are in the range of millivolt (mV).and are easily susceptible to noise. It's an easy and efficient method to find the voltage value with more accuracy.

For better accuracy of the sampled data, the arithmetic mean of 1500 samples is considered for measuring the temperature. We sampled the data at a rate of 1500 samples/sec. More the number of sample we take, we get the precise value of voltage.

With wide operating temperatures and multiple mounting methods, Advantech's ADAM series can be implemented in diverse applications.

The arithmetic is given by$\sum_{i=1}^{n} \frac{V}{N}$.

The data acquisition module is shown in figure 2.2. We should be very careful during the connection with breadboard.

The components of data acquisition module are:

(i) Sensor that convert the physical parameter into the electrical signal.

(ii) Signal conditioning circuitry to convert sensor signals into a form that can be converted to digital values.

(iii) Analog-to-digital converters, which convert conditioned sensor signals to digital values.

Figure 2.2: The Data Acquisition Module.

Breadboard

Figure 2.3 shows the simple breadboard which has been used for this experiment. A breadboard (proto-board) is a construction base for prototyping of electronics. The term is commonly used to refer to solder fewer breadboards (plug board)**.** Because the solder less breadboard does not require soldering, it is reusable. This makes it easy to use for creating temporary prototypes and experimenting with circuit design. Older breadboard types did not have this property. A strip board (Vero board) and similar Prototyping printed circuit boards, which are used to build permanent soldered prototypes or one-offs, cannot easily be reused. A variety of electronic systems may be prototyped by using breadboards, from small analog and digital circuits to complete central processing units. The bread board shown in figure 2.3 has interconnecting wires and lead as a discrete component such as capacitor, inductor, and resistor.

Complex circuit can also be easily drawn on the bread board and we should take care of positive and negative terminals during the connection of wire to get the accurate result.

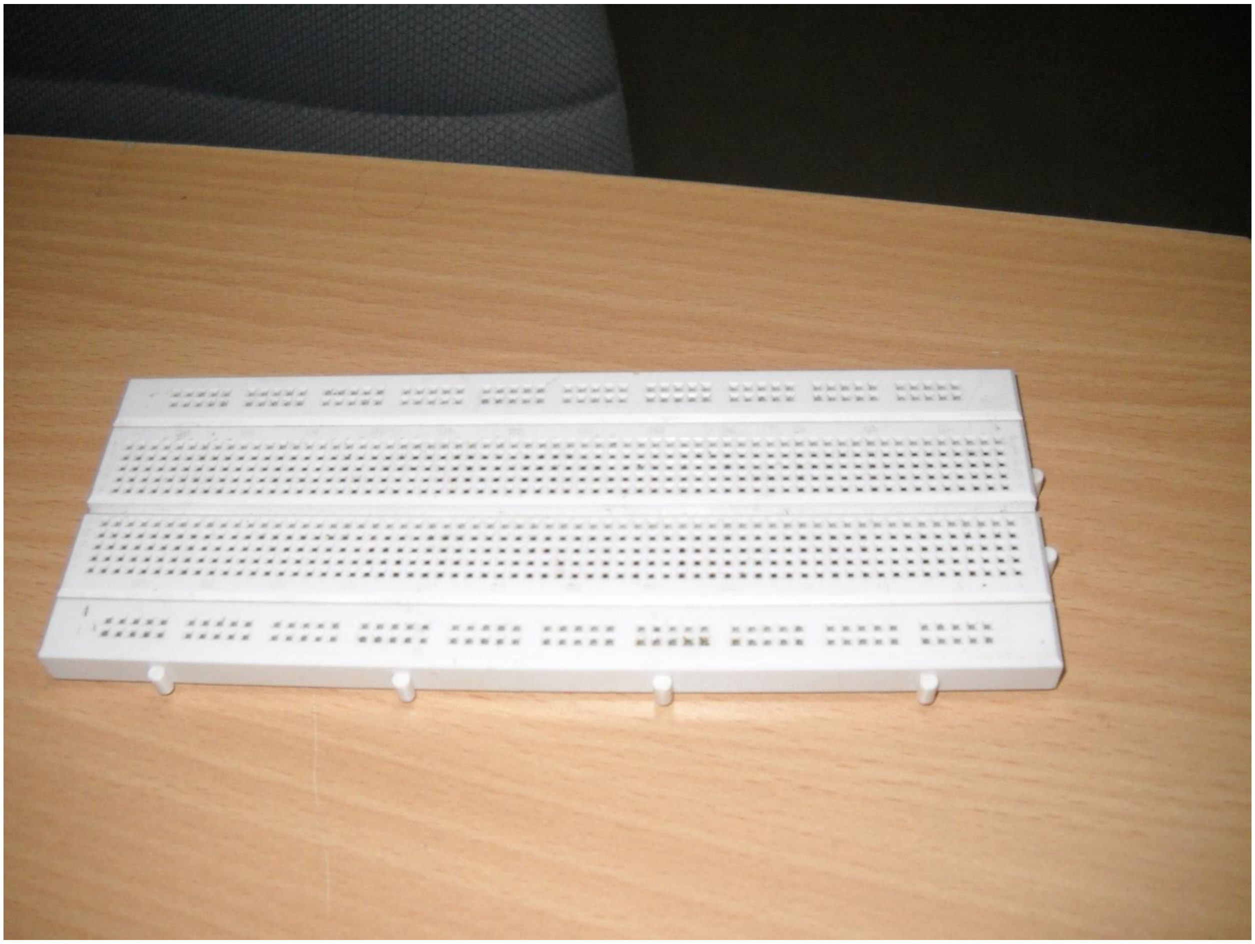

Figure 2.3: Bread Board

Calibration of thermocouple

This is the most important step in our experiment. The thermocouple is calibrated for the three different temperatures 60°C, 70°C, 80°C. During the calibration the thermocouple was inserted inside the water bath and in the open air the calibration is done to decrease the error during the experiment. The error associated with the measurement was in the range of ± 2^{0}C.

The overall setup connected with computer

This is the complete setup connected with the computer to measure the thermal conductivity of gel. The setup which we have design is connected with bread board and data acquisition and a computer with installed lab view to monitor the master file to get the corresponding temperature. The complete set-up consists of the following:

1 set-up

2 thermocouple wire

3 agarose gel

4 water bath

5 data acquisition module

6 computer with installed Lab view

7 thermo meter

By this technique we can determine the temperature dependent thermal conductivity of different tissue. The information obtained with this experiment can be utilized for the treatment of many kind of cancer diseases including sarcoma and melanoma.

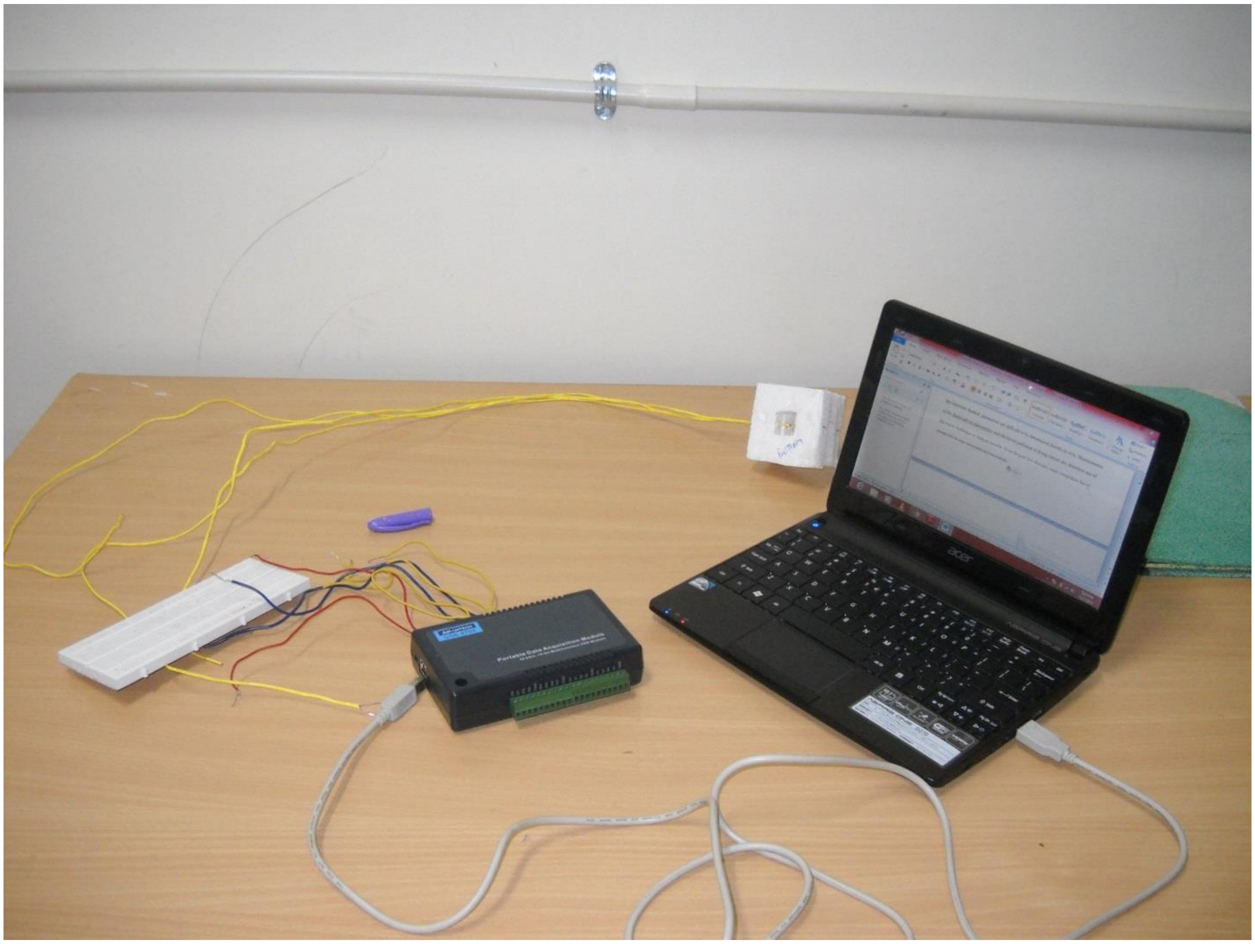

Figure 2.4 Shows the Complete Set-up of Experiment

Chapter 3

Result and discussion

Chapter 3

Result and discussion

The thermal conductivity of tissue mimicking gel (agarose gel) is predicted for two different concentrations of agarose, viz. 0.6% and 1.4%. The other properties of agarose gel are listed in table 1. As the concentration of agar is very low, the value of density and specific heat capacity

Table 1: The properties of agarose gel

Property	**Value**
Density (ρ)	1000 Kg/m^3
Specific heat capacity (c_p)	4200 J/Kg-K

is taken equal to that of the value of water. The thermal conductivity of agarose gel is obtained for three different temperatures of water bath (60°C, 70°C, 80°C). It is assumed that the thermal conductivity for a given condition is same, i.e. it does not vary with temperature.

Water bath temperature $60^{o}C$ and concentration of the sample 0.6%.

Figure 3.1 shows the temperature profile at the two locations (i.e. at 3mm from the exposed surface, termed as side location, and the mid plane of the gel sample) of agarose gel when dipped inside the water bath kept at the temperature of $60^{0}C$. The initial temperature of agarose gel is $22^{0}C$. In the figure, both the experimental and numerical results are shown. The solid line with square symbol corresponds to the temperature variation with time at the side location while the solid line with circle symbol corresponds to the temperature variation with time at the middle location (or the symmetry plane) of the gel sample. It is quite obvious that after placing the set-up inside the water bath the temperature at the nearest location from the exposed surface increases rapidly as compared to the temperature rise at the farthest location. The similar feature can be noticed in figure 3.1 where the temperature at side location increases rapidly with time as compared to the middle location. It should be noted that the numerical results are obtained after solving the one dimensional unsteady heat transfer conduction equation with the Robbin's condition at the exposed surface. The value of thermal conductivity is chosen in such a manner so that the numerically predicted temperature variation fits reasonably well with the experimental observations. Also, it is made sure that the goodness of fit should be greater than 98%. The predicted thermal conductivity at $60^{0}C$ temperature of water bath and 0.6% concentration of agarose gel is 0.6 W/m/k.

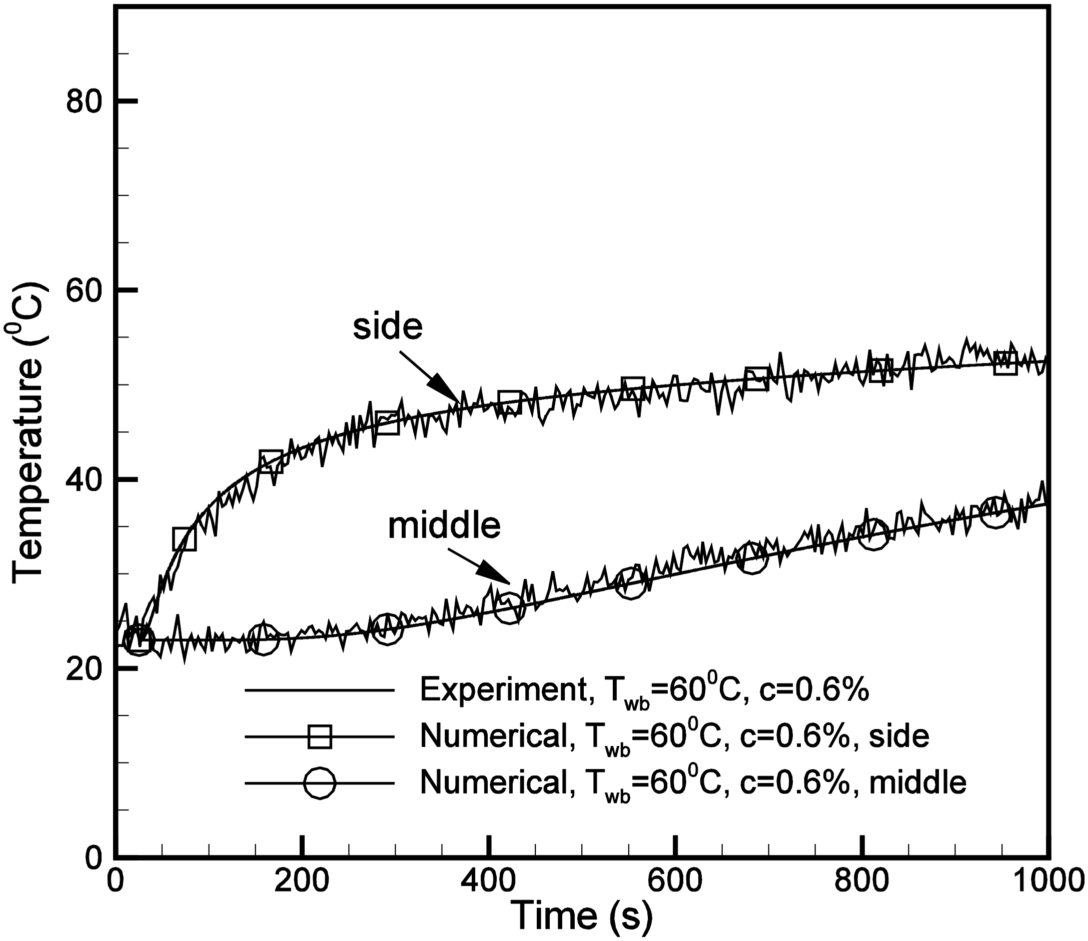

Figure 3.1: Temperature variation at the two locations when water bath temperature is 60°C and the concentration of agarose is 0.6%.

Water bath temperature 70^{o}C and concentration of the sample 0.6%.

Figure 3.2 shows the temperature profile at the two locations (i.e. at 3mm from the exposed surface, termed as side location, and the mid plane of the gel sample) of agarose gel when dipped inside the water bath kept at the temperature of 70^{0}C. The initial temperature of agarose gel is 22^{0}C. In the figure, both the experimental and numerical results are shown. The solid line with square symbol corresponds to the temperature variation with time at the side location while the solid line with circle symbol corresponds to the temperature variation with time at the middle location (or the symmetry plane) of the gel sample. It should be noted that there is a sudden increase in the temperature at the side location as soon as the set up is dipped inside the water bath. Also, the rise is more as compared to the previous case of the water bath temperature of 60^{0}C. This is quite obvious because with the increase in the water bath temperature, keeping the initial temperature of the gel same, there is large initial temperature gradient at the surface which induces sudden increase in the temperature at the side location. Although, the rise in temperature at the middle location is not quick as is the case with the side location but the rise is more compared to the rise in the previous case of 60^{0}C. It should be noted that the numerical results are obtained after solving the one dimensional unsteady heat transfer conduction equation with the Robbin's condition at the exposed surface. The value of thermal conductivity is chosen in such a manner so that the numerically predicted temperature variation fits reasonably well with the experimental observations. Also, it is made sure that the goodness of fit should be greater than 98%. The predicted thermal conductivity at 70^{0}C temperature of water bath and 0.6% concentration of agarose gel is 0.7 W/m/k.

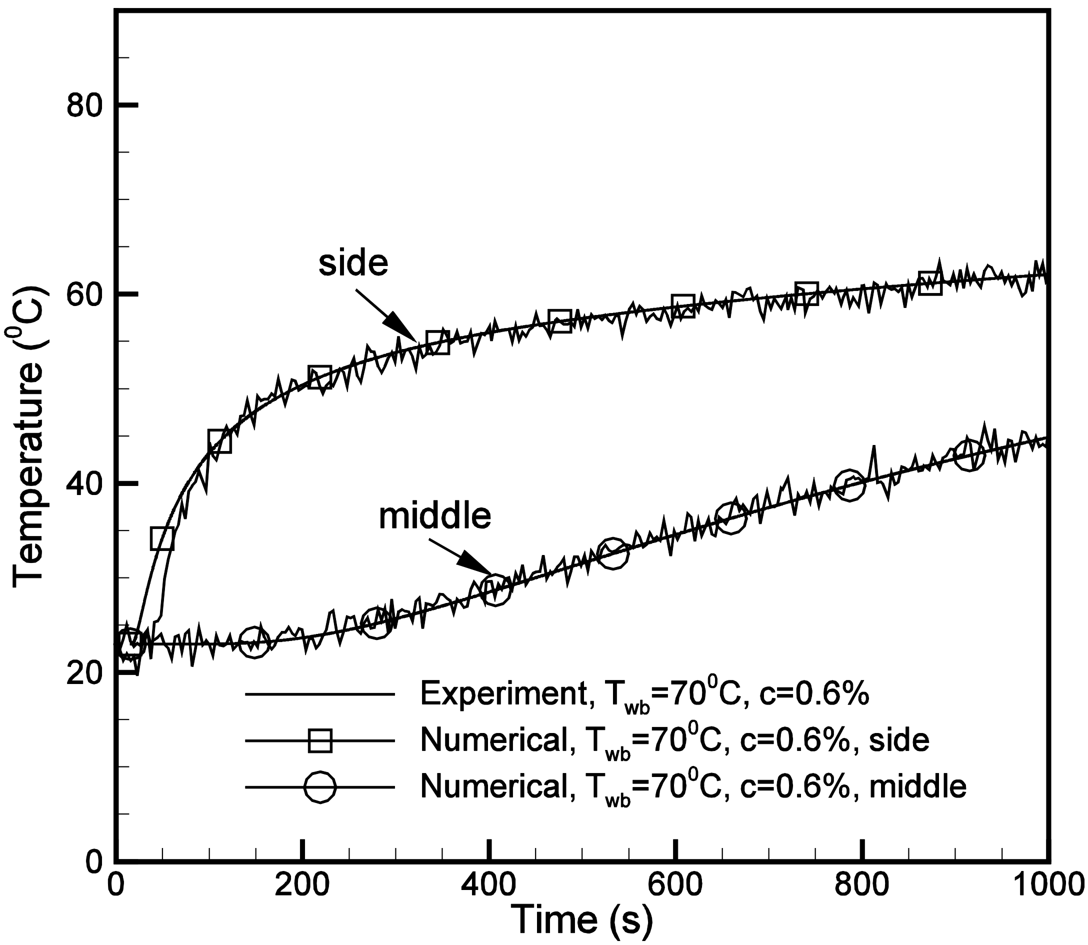

Figure 3.2: Temperature variation at the two locations when water bath temperature is 70°C and the concentration of agarose is 0.6%.

Water bath temperature 80^{o}C and concentration of the sample 0.6%.

Figure 3.3 shows the temperature profile at the two locations (i.e. at 3mm from the exposed surface, termed as side location, and the mid plane of the gel sample) of agarose gel when dipped inside the water bath kept at the temperature of 80^{0}C. The initial temperature of agarose gel is 22^{0}C. In the figure, both the experimental and numerical results are shown. The solid line with square symbol corresponds to the temperature variation with time at the side location while the solid line with circle symbol corresponds to the temperature variation with time at the middle location (or the symmetry plane) of the gel sample. With the further increase in the water bath temperature to 80^{0}C, keeping the initial temperature of the gel same, there is a further increase in the initial temperature gradient at the exposed surface which drives the heat transfer more rapidly inside the gel sample. As a result, the temperature variation at the side and the middle locations rises more rapidly compared to the previous two cases. It should be noted that the numerical results are obtained after solving the one dimensional unsteady heat transfer conduction equation with the Robbin's condition at the exposed surface. The value of thermal conductivity is chosen in such a manner so that the numerically predicted temperature variation fits reasonably well with the experimental observations. Also, it is made sure that the goodness of fit should be greater than 98%. The predicted thermal conductivity at 80^{0}C temperature of water bath and 0.6% concentration of agarose gel is 0.8 W/m/k. Therefore, it is interesting to note that the thermal conductivity increases almost linearly with the increase in the water bath temperature.

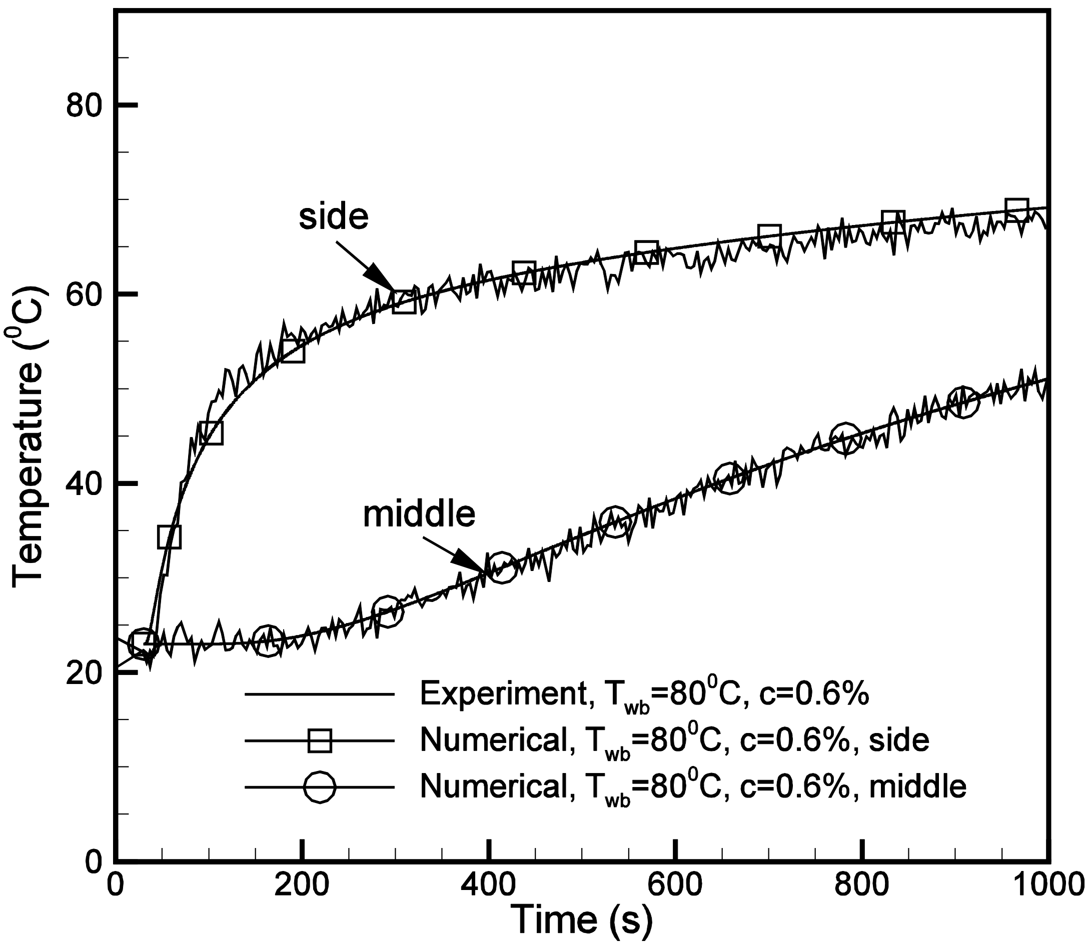

Figure 3.3: Temperature variation at the two locations when water bath temperature is 80°C and the concentration of agarose is 0.6%.

Water bath temperature 60^{o}C and concentration of the sample 1.4%.

Figure 3.4 shows the temperature profile at the two locations (i.e. at 3mm from the exposed surface, termed as side location, and the mid plane of the gel sample) of agarose gel when dipped inside the water bath kept at the temperature of 60^{0}C. It should be noted that the initial temperature of agarose gel is 30^{0}C. The above temperature is the steady state temperature of the sample when it is left in the atmospheric air to cool down. For the previous case, this temperature was 22^{0}C. In the figure, both the experimental and numerical results are shown. The solid line with square symbol corresponds to the temperature variation with time at the side location while the solid line with circle symbol corresponds to the temperature variation with time at the middle location (or the symmetry plane) of the gel sample. It is interesting to observe that the rise in temperature at either the location is not rapid as compared to the corresponding case of gel with 0.6% concentration, which indicates that the heat diffusion inside the gel is slow. It should be noted that the numerical results are obtained after solving the one dimensional unsteady heat transfer conduction equation with the Robbin's condition at the exposed surface. The value of thermal conductivity is chosen in such a manner so that the numerically predicted temperature variation fits reasonably well with the experimental observations. Also, it is made sure that the goodness of fit should be greater than 98%. The predicted thermal conductivity at 60^{0}C temperature of water bath and 1.4% concentration of agarose gel is 0.55 W/m/k. This indicates that the thermal conductivity of agarose gel decreases with the increase in the concentration of agarose.

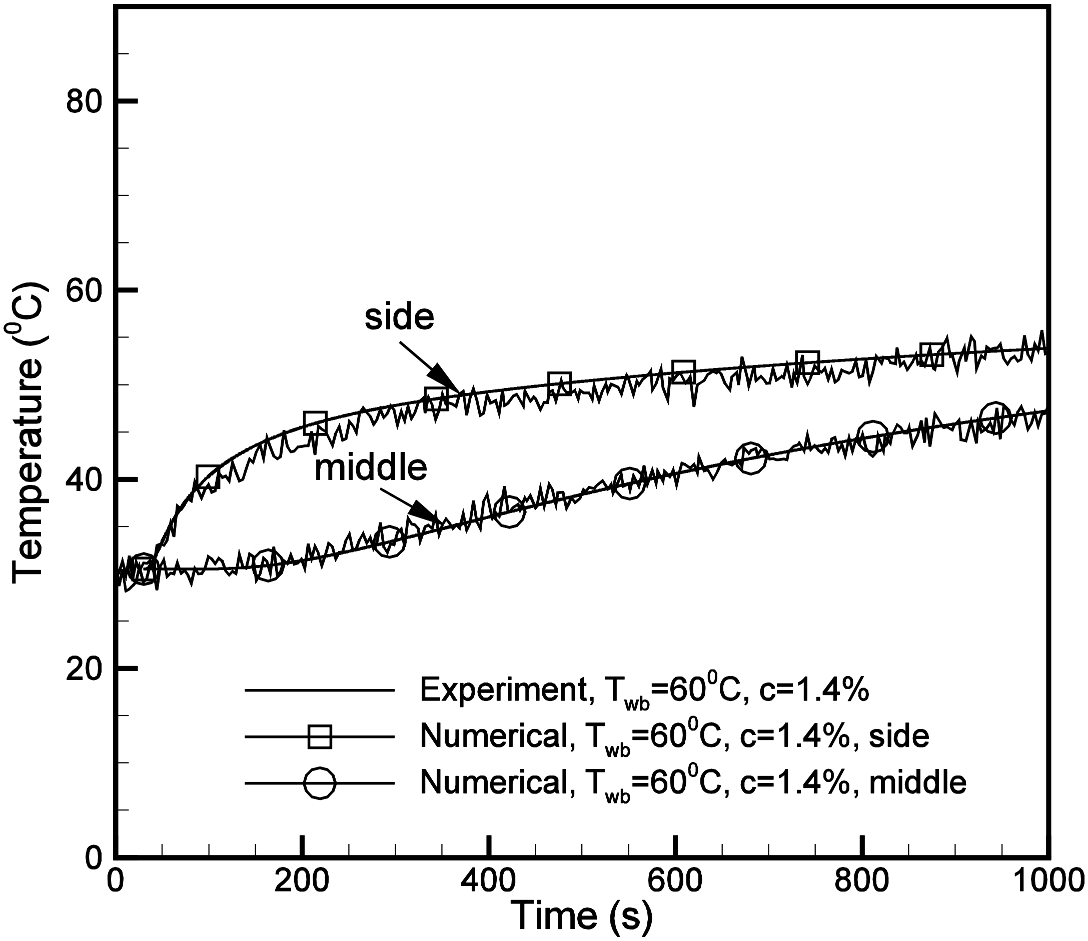

Figure 3.4: Temperature variation at the two locations when water bath temperature is 60^{o}C and the concentration of agarose is 1.4%.

Water bath temperature 70^{o}C and concentration of the sample 1.4%.

Figure 3.5 shows the temperature profile at the two locations (i.e. at 3mm from the exposed surface, termed as side location, and the mid plane of the gel sample) of agarose gel when dipped inside the water bath kept at the temperature of 70^{0}C. In this case also the initial temperature of agarose gel is 30^{0}C. In the figure, both the experimental and numerical results are shown. The solid line with square symbol corresponds to the temperature variation with time at the side location while the solid line with circle symbol corresponds to the temperature variation with time at the middle location (or the symmetry plane) of the gel sample. Similar trends have been observed for this case also; compared to the corresponding case with 0.6% concentration of agarose, the rise in temperature is slower which again reflects that the thermal conductivity should be lower than the corresponding case with 0.6% agarose concentration. But, the rise is more compared to the similar case when water bath temperature is 60^{0}C. However, the difference between the temperatures at the two locations, at any instant, is less compared to the corresponding case with 0.6% of agarose concentration. It should be noted that the numerical results are obtained after solving the one dimensional unsteady heat transfer conduction equation with the Robbin's condition at the exposed surface. The value of thermal conductivity is chosen in such a manner so that the numerically predicted temperature variation fits reasonably well with the experimental observations. Also, it is made sure that the goodness of fit should be greater than 98%. The predicted thermal conductivity at 70^{0}C temperature of water bath and 1.4% concentration of agarose gel is 0.65 W/m/k.

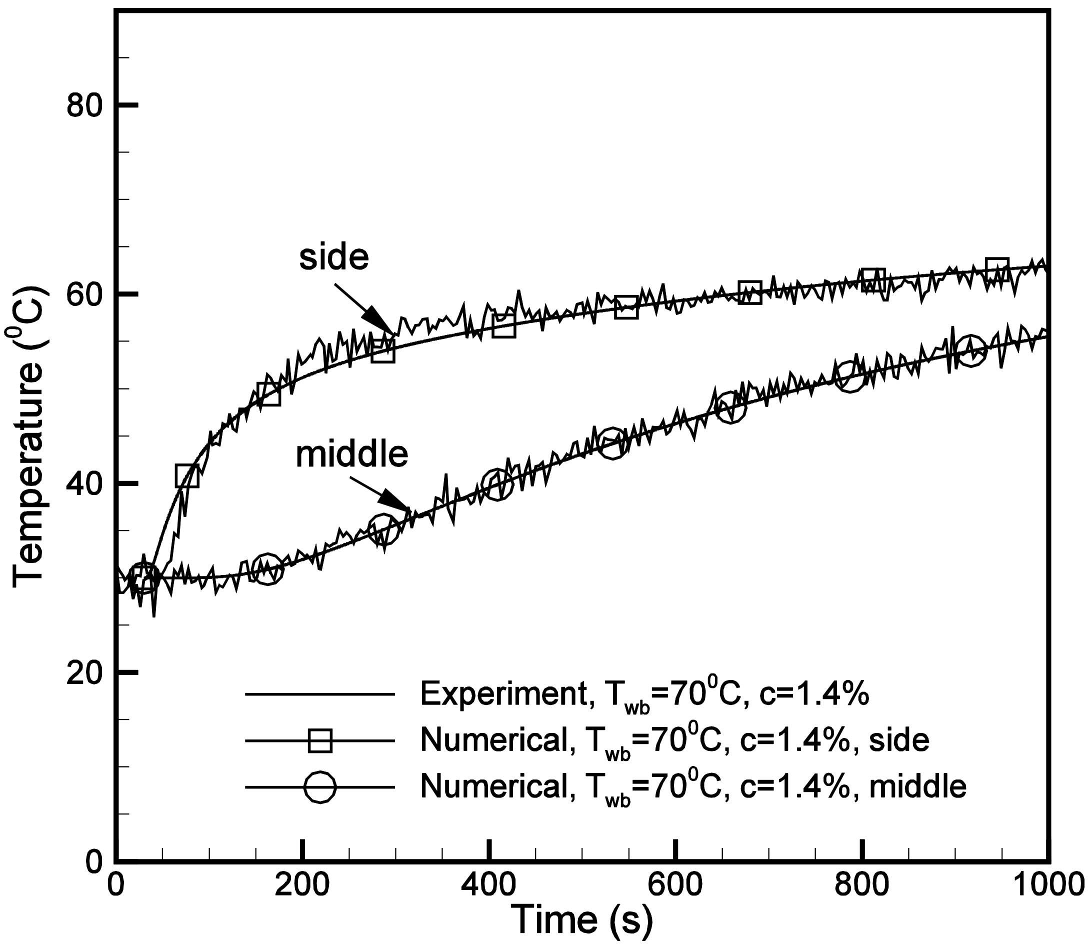

Figure 3.5: Temperature variation at the two locations when water bath temperature is 70°C and the concentration of agarose is 1.4%.

Water bath temperature 80^{o}C and concentration of the sample 1.4%.

Figure 3.6 shows the temperature profile at the two locations (i.e. at 3mm from the exposed surface, termed as side location, and the mid plane of the gel sample) of agarose gel when dipped inside the water bath kept at the temperature of 80^{0}C. The initial temperature of agarose gel is 30^{0}C. In the figure, both the experimental and numerical results are shown. The solid line with square symbol corresponds to the temperature variation with time at the side location while the solid line with circle symbol corresponds to the temperature variation with time at the middle location (or the symmetry plane) of the gel sample. With the further increase in the water bath temperature to 80^{0}C, keeping the initial temperature of the gel same, there is a further increase in the initial temperature gradient at the exposed surface which drives the heat transfer more rapidly inside the gel sample. As a result, the temperature variation at the side and the middle locations rises more rapidly compared to the previous two cases (figure 3.4 and figure 3.5). Although, the rise of temperature at the two locations is more compared to the previous two cases but it is less compared to the corresponding case with 0.6% of agarose concentration (as can be seen in figure 3.3). It should be noted that the numerical results are obtained after solving the one dimensional unsteady heat transfer conduction equation with the Robbin's condition at the exposed surface. The value of thermal conductivity is chosen in such a manner so that the numerically predicted temperature variation fits reasonably well with the experimental observations. Also, it is made sure that the goodness of fit should be greater than 98%. The predicted thermal conductivity at 80^{0}C temperature of water bath and 1.4% concentration of agarose gel is 0.75 W/m/k. It can be noticed that, like in previous case, the thermal conductivity increases linearly with increase in the water bath temperature.

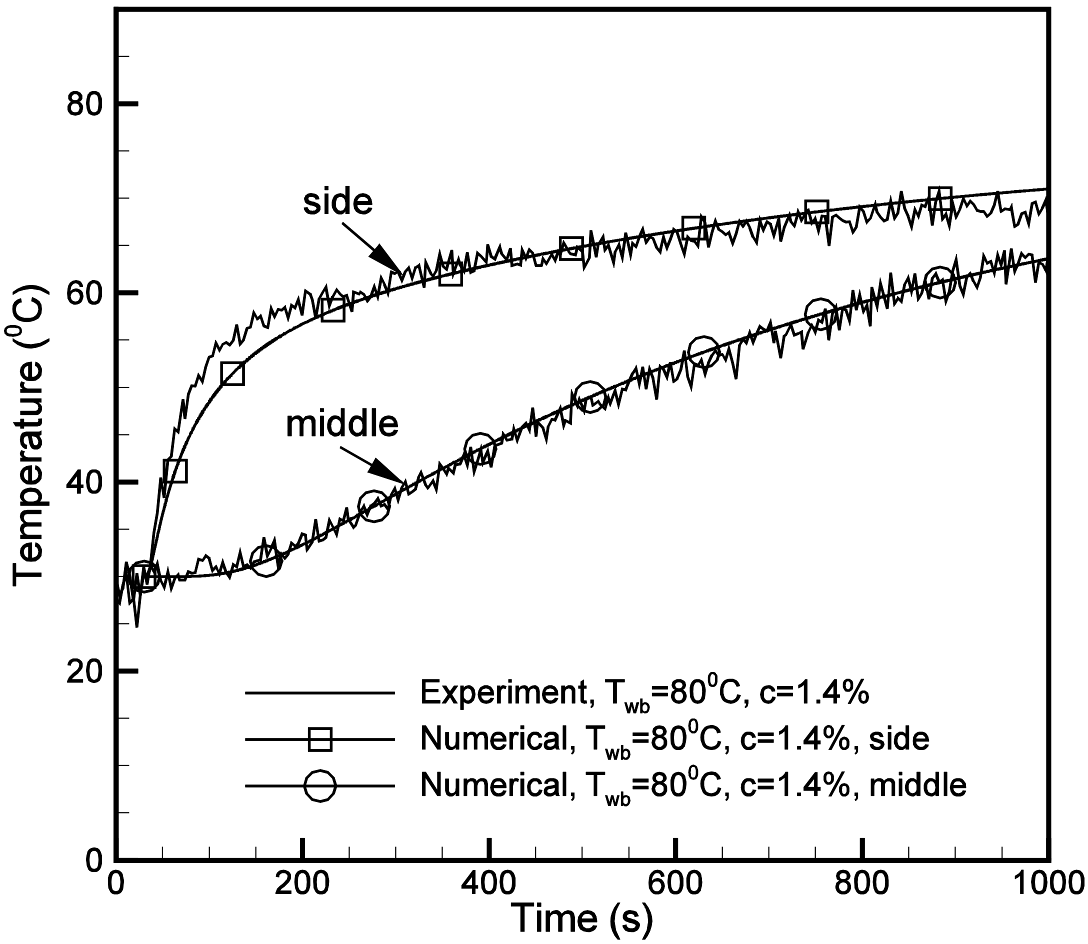

Figure 3.6: Temperature variation at the two locations when water bath temperature is 80°C and the concentration of agarose is 1.4%.

Conclusion

In the present investigation, the thermal conductivity of agarose gel has been studied for different concentrations of agarose and for different temperature conditions. The thermal conductivity is predicted using both the experimental and numerical techniques. First, the experimental results are obtained and then the numerical results are fitted with a goodness of fit not less than 98%, which provided the desired thermal conductivity. It has been found that the thermal conductivity is a function of both the temperature and the concentration of agarose. The thermal conductivity is found to increase linearly with the increase in temperature and is found to decrease with the increase in the concentration of agarose keeping other parameters same.

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